APPLICATION FOR UNITED STATES LETTERS PATENT

for

AUTOMATED METHODS OF DETECTING RECEPTOR ACTIVITY

by

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AUTOMATED METHODS OF DETECTING RECEPTOR ACTIVITY

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 60/275,339, filed March 13, 2001, the entire disclosure of which is incorporated herein by reference.

STATEMENT REGARDING FEDERALLY-SPONSORED RESEARCH OR DEVELOPMENT

[0002] This work was supported by the U.S. Government under Grant No. HL61365 awarded by the National Institutes of Health. The U.S. Government may have certain rights in the invention.

BACKGROUND

[0003] The present invention relates to methods of detecting G protein-coupled receptor (GPCR) activity *in vitro* and *in vivo*. The present invention provides methods for identifying compounds that activate the GPCR regulatory pathway and methods for identifying ligands of GPCRs.

[0004] G protein-coupled receptors (GPCRs) are cell surface proteins that translate hormone or ligand binding into intracellular signals. GPCRs are found in all animals, insects, and plants. GPCR signaling plays a pivotal role in regulating various physiological functions including phototransduction, olfaction, neurotransmission, vascular tone, cardiac output, digestion, pain, and fluid and electrolyte balance. Although they are involved in various physiological functions, GPCRs share a number of common structural features. They contain seven membrane domains bridged by alternating intracellular and extracellular loops and an intracellular carboxyl-terminal tail of variable length.

[0005] The magnitude of the physiological responses controlled by GPCRs is linked to the balance between GPCR signaling and signal termination. The signaling of GPCRs is controlled by a family of intracellular proteins called arrestins. Arrestins bind activated GPCRs, including those that have been agonist-activated and especially those that have been phosphorylated by G protein-coupled receptor

kinases (GRKs).

[0006] Receptors, including GPCRs, have historically been targets for drug discovery and therapeutic agents because they bind ligands, hormones, and drugs with high specificity. Approximately fifty percent of the therapeutic drugs in use today target or interact directly with GPCRs. See eg., Jurgen Drews, (2000) "Drug Discovery: A Historical Perspective," *Science* 287:1960-1964.

[0007] Although only several hundred human GPCRs are known, it is estimated that several thousand GPCRs exist in the human genome. Of these known GPCRs, many are orphan receptors that have yet to be associated with a function or ligands.

[0008] One method of assaying GPCR activity, as disclosed in U.S. Patent No. 5,891,646, and No. 6,110,693, both to Barak et al., uses a cell expressing a GPCR and a conjugate of an arrestin and a detectable molecule.

[0009] Accordingly, there is a need to provide accurate, easy to interpret methods of detecting G protein-coupled receptor activity.

SUMMARY

[0010] In accordance with one aspect of the present invention, a method of detecting G protein-coupled receptor (GPCR) pathway activity is provided. The method includes providing at least one cell that expresses a GPCR and a plurality of conjugated proteins. Each of the plurality of conjugated proteins is formed by conjugating an arrestin protein and a detectable molecule. The plurality of conjugated proteins are substantially evenly distributed in the cytoplasm of the at least one cell. A first image of the at least one cell is obtained by detecting an amount of energy emitted from the detectable molecules and storing a value relative to the amount of energy. The at least one cell is treated with a test compound. A second image of the at least one cell is obtained. The first image and the second image are compared to detect the localization of at least some of the plurality of conjugated proteins. The localization may occur at endocytic vesicles and/or endosomes.

[0011] In accordance with another aspect of the invention, a method of detecting G protein-coupled receptor (GPCR) pathway activity is provided whereby at least one cell that expresses a GPCR and a plurality of conjugated proteins are provided.

Each of the plurality of conjugated proteins is formed by conjugating an arrestin protein and a detectable molecule. The plurality of conjugated proteins are substantially evenly distributed in the cytoplasm of the at least one cell. A first digital image of the at least one cell is obtained by detecting and measuring energy emitted from the detectable molecules. The first digital image is formed from an array of a plurality of pixels each having respective intensity values. A respective intensity value is based on the intensity of energy emitted from the detectable molecules associated with a pixel's location in the array. The at least one cell is treated with a test compound. A second digital image of the at least one cell is obtained by detecting and measuring energy emitted from the detectable molecules. The second digital image is formed from an array of a plurality of pixels each having respective intensity values. A respective intensity value is based on the intensity of energy emitted from the detectable molecules associated with a pixel's location in the array. The first digital image and the second digital image are compared to detect the localization of at least some of the plurality of conjugated proteins. The localization may occur at endocytic vesicles and/or endosomes. The localization of at least some of the plurality of conjugated proteins are detected by a change in apparent intensity of energy emitted from detectable molecules resulting in an increase in the value of at least some of the plurality of pixels.

[0012] In accordance with yet another aspect of the invention, a method of detecting G protein-coupled receptor (GPCR) pathway activity is provided. At least one cell that expresses a GPCR and a plurality of conjugated proteins is provided. Each of the plurality of conjugated proteins is formed by conjugating an arrestin protein and a detectable molecule. The plurality of conjugated proteins are substantially evenly distributed in the cytoplasm of the at least one cell. The at least one cell is treated with a test compound. A digital image of the at least one cell is obtained by detecting and measuring energy emitted from the detectable molecules. The digital image is formed from an array of a plurality of pixels each having respective intensity values. A respective intensity value is based on the intensity of energy emitted from the detectable molecules associated with a pixel's location in the array. The localization of at least some of the plurality of conjugated proteins may be detected at endocytic vesicles and/or endosomes. The localization of at

least some of the plurality of conjugated proteins is detected by a change in apparent intensity of energy emitted from detectable molecules resulting in a value of at least some of the plurality of pixels above a threshold intensity.

[0013] It should be emphasized that the term "comprises" or "comprising," when used in this specification, is taken to specify the presence of stated features, steps, or components, but does not preclude the presence or addition of one or more other features, steps, components, or groups thereof.

BRIEF DESCRIPTION OF DRAWINGS

[0014] The objects and advantages of the invention will be understood by reading the following detailed description in conjunction with the drawings in which:

Figure 1 is a flow diagram of a method of detecting receptor activity in accordance with the invention;

Figure 2 is a flow diagram of another method of detecting receptor activity in accordance with the invention;

Figures 3a and 3b are confocal microscopic images of βarr-GFP fluorescence in cells stably expressing βarr-GFP fusion protein and the V2R (GPCR) of which:

Figure 3a is before treatment with an agonist (Control) and

Figure 3b is after a 30 min. treatment with agonist at 37°C;

Figures 4a and 4b are identical to Figures 3a and 3b, respectively, except that they were taken at a reduced detector sensitivity to prevent saturation of the detector;

Figures 5a and 5b show confocal microscope images taken at reduced intensity with the pixels above the threshold intensity (here calculated as those within the >99th percentile) appearing as lightly shaded regions, of which:

Figure 5a is of the control group and

Figure 5b is of the treated cells;

Figure 6 is a histogram of pixel count vs pixel intensity; and

Figure 7 is a graph of the number of pixels above the threshold intensity for the control and treated cells.

DETAILED DESCRIPTION

[0015] Automated screening methods to detect GPCR pathway activity are provided. The methods may be used to determined whether the level of GPCR pathway has changed. The methods provide convenient, real time, high volume methods of screening compounds and/or solutions for GPCR activity.

[0016] The methods offer the advantage of providing a gross comparison of the relative intensities of scans of cells before and after exposure to a test compound for a quick and simple determination of the activity of the test compound. Examples of test compounds include potential ligands, potential agonists, potential antagonists, and potential desensitization agents. The methods do not require qualitative analyzes of an image with respect to location of a detectable molecule and the detectable molecule's proximity to any specific cell structure. The method also does not require determinations of area of specific cell structures or any measurements within the cell nucleus. The methods will facilitate the rapid screening of compounds in an automated process.

[0017] Examples of assays with which the methods may be used include, but are not limited to, those as described in U.S. Patent Nos. 5,891,646 and 6,110,693, and U.S. Application Serial No. 09/993,844, filed November 5, 2001, the disclosures of which are hereby incorporated by reference in their entirety. Additional examples of assays with which the methods may be used include, but are not limited to, assays using Fluorescent Resonance Energy Transfer (FRET) and assays using Bioluminescence Resonance Energy Transfer (BRET) technology as described in Angers, S., Salahpour, A., Joly, E., Hilairet, S., Chelsky, "β2-adrenergic receptor dimerization in living cells using bioluminescence resonance energy transfer (BRET)," *Proc. Nat'l. Acad. Sci.* USA 97, 7: 3684-3689.

[0018] Through a process called desensitization, G protein-coupled receptor kinases (GRKs) phosphorylate intracellular domains of GPCRs, for example, at the carboxyl-terminal tail. The carboxyl-terminal tail of many GPCRs begins shortly after the conserved NPXXY motif that marks the end of the seventh transmembrane domain (i.e. what follows the NPXXY motif is the carboxyl-terminal tail of the GPCR). The carboxyl-terminal tail may be relatively long (approximately tens to hundreds of amino acids), relatively short (approximately tens of amino acids), or virtually

non-existent (less than approximately ten amino acids). As used herein, "carboxyl-terminal tail" shall mean all three variants (whether relatively long, relatively short, or virtually non-existent).

[0019] After phosphorylation, an arrestin protein associates with the GRK-phosphorylated receptor and uncouples the receptor from its cognate G protein. It will be understood that the term "arrestin" refers to all types of naturally occurring and engineered variants of arrestin, including, but not limited to, visual arrestin (sometimes referred to as Arrestin 1), β-arrestin 1 (sometimes referred to as Arrestin 2), and β-arrestin 2 (sometimes referred to as Arrestin 3). The interaction of the arrestin with the phosphorylated GPCR terminates GPCR signaling and produces a non-signaling, desensitized receptor.

[0020] The arrestin bound to the desensitized GPCR targets the GPCR to clathrin-coated pits for endocytosis. The stability of the interaction of arrestin with the GPCR may dictate the rate of GPCR dephosphorylation, recycling, and resensitization. When the GPCR has an enhanced affinity for arrestin, the GPCR/arrestin complex remains intact and is internalized into endosomes.

[0021] To monitor GPCR activity, an *in vivo* or *in vitro* environment may be utilized. In both environments, a conjugate of an arrestin protein and a detectable molecule is utilized. The term "detectable molecule" means any molecule capable of detection by spectroscopic, photochemical, biochemical, immunochemical, electrical, radioactive, and optical means, including but not limited to, fluorescence, phosphorescence, and bioluminescence and radioactive decay. Detectable molecules include, but are not limited to, GFP, luciferase, β-galactosidase, rhodamine-conjugated antibody, and the like. Detectable molecules include radioisotopes, epitope tags, affinity labels, enzymes, fluorescent groups, chemiluminescent groups, and the like. Detectable molecules include molecules which are directly or indirectly detected as a function of their interaction with other molecule(s).

[0022] GFP includes various naturally occurring forms of GFP that may be isolated from natural sources or genetically engineered, as well as artificially modified GFPs. GFPs are well known in the art. See, for example, U.S. Patent Nos. 5,625,048; 5,777,079; and 6,066,476. It is well understood in the art that GFP is readily

interchangeable with other fluorescent proteins, isolated from natural sources or genetically engineered, including, but not limited to, yellow fluorescent proteins (YFP), red fluorescent proteins (RFP), cyan fluorescent proteins (CFP), UV excitable fluorescent proteins, or any wave-length in between.

[0023] The methods are designed to detect changes in the location of the conjugate of an arrestin protein and a detectable molecule after exposure of the cells to test compounds, test solutions, and test conditions.

[0024] In an *in vivo* environment, one or more cells that express a GPCR and that contain a conjugate of an arrestin protein and a detectable molecule are provided. Arrestin coupled to a detectable molecule may be detected and monitored. The location of the arrestin may be detected, for example, evenly distributed in the cell cytoplasm, concentrated at a cell membrane, and/or localized in endocytic vesicles. In response to agonist stimulation, the proximity of arrestin to a GPCR may be monitored, as well as the proximity to any other cell structure. For example, in response to agonist stimulation arrestin may be detected in proximity to GPCRs at a cell membrane and/or colocalized with a GPCR in endocytic vesicles.

[0025] In an *in vitro* environment, a substrate having deposited thereon one or more GPCRs having arrestin binding sites and agonist binding sites is provided, and a buffered solution comprising one or more conjugates of an arrestin protein and a detectable molecule is provided. The GPCR can be positioned on the substrate such that the arrestin binding sites are exposed to the arrestin and the agonist binding sites are accessible to agonists. The GPCR and arrestin may be obtained from whole cells and used in the *in vitro* assay after purification. The GPCR has arrestin binding sites and agonist binding sites and may be supported in a multilayer or bilayer lipid vesicle. The vesicle supporting the GPCR is deposited on the substrate, and the GPCR is supported in the lipid vesicle and deposited on the substrate such that the arrestin binding sites are exposed to arrestin and the receptor binding sites are accessible to agonists. The substrate may be any artificial substrate on which the modified GPCR may be deposited, including but not limited to, glass, plastic, diamond, ceramic, semiconductor, silica, fiber optic, biocompatible monomer, biocompatible polymer, polymer beads (including organic and inorganic polymers), and the like.

[0026] The location of the arrestin may be detected and monitored in the *in vitro* environment. In response to agonist stimulation, the redistribution of arrestin may be detected. For example, in response to agonist stimulation, arrestin may be detected in proximity to GPCRs on the substrate, arrestin may be detected to compartmentalize, and the like.

GPCRs

[0027] The method may be utilized with any membrane receptor protein in which agonist binding is linked to association of arrestin proteins. An illustrative, non-limiting list of known GPCRs with which the present invention may be used is contained in Table 1. The receptors are grouped according to classical divisions based on structural similarities and ligands. GPCRs that may be used in the present invention include known GPCRs, unknown or orphan GPCRs, and chimeric or modified GPCRs. A GPCR is considered to be an "unknown or orphan GPCR" if its function and/or ligands are unknown. Modified GPCRs include GPCRs that have one or more modifications in the carboxyl-terminal tail, modifications in the intracellular loop(s), and/or in the cytoplasmic end of the transmembrane region, preferably in the carboxyl-terminal tail.

[0028] By way of example, three major classes of GPCRs for known receptors have been identified: Class A receptors, Class B receptors, and receptors with virtually non-existent carboxyl-terminal tails. The receptors are classified accordingly based on their interactions with and affinity for rat β-arrestin-2 in HEK-293 cells and may be predicted based on the amino acid residues in their carboxyl-terminal tail and the length of their carboxyl-terminal tail. A Class B receptor is a GPCR that has one or more sites of phosphorylation, preferably clusters of phosphorylation sites, properly positioned in its carboxyl-terminal tail such that it does recruit rat β-arrestin-2 to endosomes in HEK-293 cells under conditions as described in U.S. Patent No 5,891,646 and Oakley, et al. "Differential Affinities of Visual Arrestin, βArrestin1, and βArrestin2 for G Protein-coupled Receptors Delineate Two Major Classes of Receptors," Journal of Biological Chemistry, Vol 275, No. 22, pp 17201-17210, June 2, 2000, the contents of which are hereby incorporated by reference in their entirety. A Class A receptor is a GPCR that does not have one or more sites of

phosphorylation, preferably clusters of phosphorylation sites, properly positioned in its carboxyl-terminal tail such that it does not recruit rat β-arrestin-2 to endosomes in HEK-293 cells under conditions as described above for Class B receptors. Receptors with virtually non-existent carboxyl-terminal tails include, for example, olfactory and taste receptors.

[0029] Table 2 is an illustrative, non-limiting list of known receptors, including the amino acid sequence for their carboxyl terminal tails and appropriate classification. For the Class B receptor examples, the residues that may function as clusters of phosphorylation sites are shown in bolded italics.

[0030] In the present invention, modified GPCRs are preferred. The modified GPCRs include GPCRs that have been modified to have one or more sites of phosphorylation, preferably clusters of phosphorylation sites, properly positioned in its carboxyl-terminal tail. These clusters of phosphorylation sites are preferably serine and threonine residues located in the carboxyl-terminal tail of the GPCR. These clusters are remarkably conserved in their position within the carboxyl-terminal tail domain and serve as primary sites of agonist-dependent phosphorylation. The clusters of amino acids may occupy two out of two, two out of three, three out of three, three out of four, four out of four, four out of five, five out of five, and the like consecutive amino acid positions. Accordingly, the clusters of amino acids that promote formation of a stable GPCR/arrestin complex are "clusters of phosphorylation sites."

[0031] The modified GPCRs containing one or more sites of phosphorylation, preferably clusters of phosphorylation sites, properly positioned in its carboxyl-terminal tail have an increased affinity for arrestin and colocalize with arrestin in endosomes after stimulation with agonist. These modified GPCRs recruit arrestin to endosomes within approximately 30 minutes of agonist stimulation. The one or more sites of phosphorylation, preferably clusters of phosphorylation sites, must be optimally positioned within the GPCR tail for the GPCR to have an increased affinity for arrestin.

[0032] The modified GPCRs may be constructed such that the one or more sites of phosphorylation, preferably clusters of phosphorylation sites, are optimally positioned within the carboxyl-terminal tail. The portions of polypeptides, which are

to be fused together to form the modified GPCR, are chosen such that the one or more sites of phosphorylation, preferably clusters of phosphorylation sites, are reliably positioned properly within the carboxyl-terminal tail. In the alternative, the location of discrete point mutations to create the modified GPCR may be chosen so that the one or more sites of phosphorylation, preferably clusters of phosphorylation sites, are properly positioned within the carboxyl-terminal tail.

Cells

[0033] Cells useful in the present invention include eukaryotic and prokaryotic cells, including, but not limited to, bacterial cells, yeast cells, fungal cells, insect cells, nematode cells, plant cells, and animal cells. Suitable animal cells include, but are not limited to, HEK cells, HeLa cells, COS cells, U208 cells, and various primary mammalian cells. An animal model expressing a conjugate of an arrestin and a detectable molecule throughout its tissues or within a particular organ or tissue type, may be useful in studying cellular targets of known or unknown GPCR ligands.

[0034] Cells useful in the present invention include those that express a known GPCR, a variety of known GPCRs, an unknown GPCRs, a variety of unknown GPCRs, a modified GPCR, a variety of modified GPCRs, and combinations thereof. A cell that expresses a GPCR is one that contains the GPCR as a functional receptor in its cell membrane. The cells may naturally express the GPCRs or may be genetically engineered to express the GPCRs. As one skilled in the art readily would understand, the cells may be genetically engineered to express GPCRs by molecular biological techniques standard in the genetic engineering art.

The Conjugates

[0035] In the methods of the present invention, a conjugate of an arrestin protein and a detectable molecule is utilized.

[0036] All forms of arrestin, both naturally occurring and engineered variants, including but not limited to, visual arrestin, β-arrestin 1 and β-arrestin 2, may be used in the present invention. The GPCRs of the present invention having enhanced affinity motifs in their carboxyl-terminal tails (naturally-occurring and modified) may interact to a detectable level with all forms of arrestin.

[0037] Detectable molecules that may be used to conjugate with the arrestin include, but are not limited to, molecules that are detectable by spectroscopic, photochemical, radioactivity, biochemical, immunochemical, electrical, and optical means, including but not limited to, bioluminescence, phosphorescence, and fluorescence. These detectable molecules should be biologically compatible molecules and should not compromise the ability of the arrestin to interact with the GPCR system, and the interaction of the arrestin with the GPCR system must not compromise the ability of the detectable molecule to be detected. Preferred detectable molecules are optically detectable molecules, including optically detectable proteins, such that they may be excited chemically, mechanically, electrically, or radioactively to emit fluorescence, phosphorescence, or bioluminescence. Optically detectable molecules include, for example, beta-galactosidase, firefly luciferase, bacterial luciferase, fluorescein, Texas Red, and rhodamine-conjugated antibody. More preferred detectable molecules are inherently fluorescent molecules, such as fluorescent proteins, including, for example, Green Fluorescent Protein (GFP).

[0038] The detectable molecule may be conjugated to the arrestin protein by methods as described in Barak et al. (U.S. Patent Nos. 5,891,646 and 6,110,693). The detectable molecule may be conjugated to the arrestin at the front-end, at the back-end, or in the middle. Preferably, the detectable molecules are molecules that are capable of being synthesized in the cell. The cell can be transfected with DNA so that the conjugate of arrestin and a detectable molecule is produced within the cell. As one skilled in the art readily would understand, cells may be genetically engineered to express the conjugate of arrestin and a detectable molecule by molecular biological techniques standard in the genetic engineering art.

Methods of Detection

[0039] The methods of detection can be used to determine the distribution and/or location of the detectable molecules conjugated to the arrestin protein. Thus, the methods of detection may vary depending on the detectable molecule or molecules used. The methods of detection may be used to determine the intracellular location of the arrestin protein or interaction of the arrestin protein with a GPCR, for example,

the concentration of arrestin at a cell membrane or the colocalization of arrestin protein with GPCR in an endocytic vesicle. One skilled in the art will readily be able to devise detection methods suitable for the detectable molecule or molecules used.

[0040] The detectable molecules emit, reflect, and/or absorb energy depending on the detectable molecule used. For the purposes of clarity, the term "emit" is used in this specification, but should be interpreted to include "reflect" and "absorb" unless stated otherwise. The detector and method of detection used should be suitable for recognizing and recording the type of energy emitted. The detector utilized may image the cell point by point in series or in parallel, for example, using a single photodetector or a charge-coupled device array. Such configurations of detectors are known to the art.

[0041] The detection methods may include using a detector for measuring the intensity of the energy emitted from the detectable molecules and may be operatively coupled to a computer controller for controlling the operation of the detector and performing an analysis of the signals received. The controller preferably includes a computer program product for performing analysis of the signals received from the detectors. The computer program product may be written specifically for use with the detection method or may be a commercially available program modified for use with the detection method.

[0042] For optically detectable molecules, any optical method may be used where fluorescence, bioluminescence, or phosphorescence may be measured and recorded. For example, one or more photodetectors for measuring fluorescence may be used and these photodetectors may be operatively coupled to a computer controller. A charge-coupled device array may also be used and may be operatively coupled to a computer controller.

[0043] In a preferred embodiment, arrestin may be conjugated to GFP and the arrestin-GFP conjugate may be viewed by confocal microscopy.

Automated methods of detecting GPCR pathway activity

[0044] Figure 1 is a flow diagram of a method of detecting receptor activity in accordance with one aspect of the invention. Before treatment with a potential agonist, arrestin coupled to a detectable molecule may be detected evenly

distributed in the cell cytoplasm. The detectable molecules emit energy, from which a first image may be generated. The cells are scanned according to the detection method utilized, and an image of the cells is generated. The image of the cells before treatment with an agonist will show the detectable molecules to be fairly evenly distributed in the cell cytoplasm.

[0045] The intensity of energy emitted from the detectable molecules may be measured, converted to a digital format, and represented as pixels. For example, the image may be mapped according to the position and intensity of each pixel. The pixels at a given intensity may be quantified and a mean intensity for the pixels may be calculated. The digitized image may be redisplayed on a video display.

[0046] After treatment with a test compound, the cells are again scanned according to the detection method utilized, and a second image of the cells is generated. The second image of the cells can be converted to a digital image and analyzed as before.

[0047] It may be advantageous to reduce the sensitivity of the detector to prevent saturation of the detector by the intense energy emitted from detectable molecules localized in endocytic vesicles. As can be appreciated, the sensitivity of the detector can be reduced in a number of ways, such as by using energy inhibiting filters at the detector or reducing the gain associated with the detector.

[0048] If the test compound is an agonist, then the detectable molecules may be concentrated in specific, smaller areas instead of evenly distributed over the whole area of the cell cytoplasm. If the test compound is not an agonist, then the distribution of detectable molecules would be substantially unchanged.

[0049] For example, after treating the cells with an agonist, arrestin may be detected in proximity to GPCRs at a cell membrane and/or colocalized with a GPCR in endocytic vesicles. Since the detectable molecules are concentrated in smaller areas, the energy from the detectable molecules will be concentrated and of a significantly increased intensity. The apparent increase in intensity is due to a redistribution of the detectable molecules into smaller areas, and is not due to an inherent change in the intensity of the energy produced by each detectable molecule.

[0050] The energy from detectable molecules concentrated in vesicles may be

used to readily indicate activation of the GPCR pathway; therefore, positive and ready identification of these concentrations of detectable molecules is desirable. As explained above, the detectable molecules evenly distributed in the cell cytoplasm give uniform, dilute energy emissions. In comparison, the detectable molecules concentrated in endocytic vesicles give more intense energy emissions.

[0051] Figure 2 is a flow diagram of a method of detecting receptor activity in accordance with another aspect of the invention. Based on the energy emissions obtained from detectable molecules evenly distributed in the cell cytoplasm, a mean intensity can be obtained, and from this mean intensity, a threshold intensity can be set. The threshold intensity can be set such that it excludes energy emissions from detectable molecules evenly distributed in the cell cytoplasm (i.e., background emissions), but not energy emissions from detectable molecules colocalized in, for example, endocytic vesicles (i.e., target emissions). The threshold intensity may be, for example, the mean intensity of all energy emissions in a control cell (i.e., a cell not treated with an agonist) plus a determined number of standard deviations, such as two standard deviations (95th percentile) or three standard deviations (>99th percentile). The method of determining the threshold intensity is not controlling as long as the threshold is set to exclude as much of the background emissions as possible while permitting the detection of as much of the target emissions as possible.

[0052] It should be emphasized that the first image may be taken of a control group of cells rather than the group of cells that are treated with the test compound. For example, once it is determined how much conjugated protein a particular cell line expresses, this information can be used to determine the mean intensity for the cell line. The mean intensity for the cell line can be used to set the threshold intensity in subsequent experiments.

[0053] After a threshold intensity is set, the energy emissions above the threshold intensity can be identified and quantified. The identified energy emissions may be tagged using a computer memory or the identified energy emissions may be marked in a computer generated image by changing the associated pixels to a unique color, for example, magenta. The computer generated image may be redisplayed on a video display after identifying (for example, by magenta) the portions of the image

which have energy emissions at or above the threshold intensity.

[0054] The pixels corresponding to energy emissions at or above the threshold intensity may be quantified by absolute number (i.e. they may be counted), as a percentage of the total number of pixels, or, preferably, as a weighted sum of pixels above the threshold intensity. The weights may be assigned in a variety of ways. For example, each pixel above the threshold intensity may be weighted according to its respective intensity value. The number of energy emissions above the threshold intensity may be used to determine whether and to what degree GPCRs have been activated. For example, a large number of energy emissions above the threshold may indicate activation. The number of energy emissions above the threshold intensity may also be used to determine whether and to what degree GPCRs have been deactivated. For example, very few energy emissions above the threshold may indicate deactivation.

[0055] The number of energy emissions above the threshold intensity may be used to indicate activation in a variety of ways. For example, to indicate activation, a number or a percentage of energy emissions above the threshold may be set. If this set number or percentage is exceeded, it may be determined that the GPCR pathway has been activated. Further, the number of energy emissions above the threshold in the control (i.e., untreated) cells and treated cells may be compared and a number by which the treated cells' emissions exceed the control cells' emissions may be set. If this set number is exceeded, it may be determined that the GPCR pathway has been activated.

[0056] By way of example, in the automated methods of the present invention one or more cells that express a GPCR and that contain a conjugate of an arrestin protein and a detectable molecule are provided. The cells are scanned according to the method of detection to generate an image of the cells based on the relative intensity of energy emissions from the detectable molecules. The image may be digitized and the relative intensity of energy emissions may be converted to pixel intensity values. Using the intensity of the energy emissions, activation or deactivation of the GPCR pathway may be detected. For example, a considerable amount of energy above a calculated threshold intensity may indicate activation of the GPCR pathway. Likewise, a significant decrease in the amount of energy above

a calculated threshold intensity may indicate deactivation of the GPCR pathway.

[0057] For example, a mean intensity of the first image can be calculated, either directly from the first image or by analyzing the first array of pixels. A threshold intensity may be set to exclude energy emissions from detectable molecules evenly distributed in the cell cytoplasm but not energy emissions from detectable molecules in endocytic vesicles, for example, at two or three standard deviations above the mean intensity of the energy emissions in the first image (before exposure to the test compound or solution). The energy emissions above this threshold intensity may be identified and quantified. To identify the energy emissions, the associated pixels may be tagged using a computer memory or the pixels may be changed in a computer generated image to a unique color, for example, magenta. The image may be redisplayed on a video display after identifying (for example, by magenta) those pixels which are above the threshold intensity. The pixels above the threshold intensity may be quantified as a weighted sum.

[0058] A comparison of the number of pixels above the threshold before and after exposure to the test compound or solution may be used to determine if the test compound or solution is or contains an agonist. If, for example, the test compound or solution is or contains an agonist, the number of pixels above the threshold after exposure to the agonist may dramatically increase.

[0059] The automated methods of the present invention may also be used to screen test compounds and test solutions for GPCR antagonist activity. One or more cells that express a GPCR and that contain a conjugate of an arrestin protein and a detectable molecule are provided. The cells are scanned according to the method of detection to generate a first image of the cells.

[0060] The cells are exposed to a test compound or test solution and then to a known agonist. The cells are scanned again according to the method of detection to generate a second image of the cells. The first and second images may be captured as or converted to first and second sets of pixels. The intensity of the first and second sets of pixels may be measured. As discussed above, the intensity of the first and second sets of pixels can be used to determine whether the GPCR pathway has been activated. For example, if the test compound is an antagonist, activation of the GPCR pathway would be blocked.

[0061] A comparison of the number of signals above the threshold before and after exposure to the test compound or solution and the agonist may be used to determine if the test compound or solution is or contains an antagonist. If, for example, the test compound or solution is or contains an antagonist, then the number of energy emissions above the threshold before and after exposure to the agonist and test compound or solution may remain fairly constant instead of increasing as expected due to the agonist.

[0062] The invention will be further explained by the following illustrative example, which is intended to be non-limiting.

Example: Determination of Agonist Mediated Translocation of βarr-GFP

[0063] Agonist mediated translocation of the βarr-GFP chimera from cell cytosol to endocytic vesicles was studied using a double stable cell line (stable for the βarr-GFP and the V2R), for example, HEK-293 cells or COS cells. These cells were transfected with plasmids containing cDNA for the V2R receptor and for the βarr-GFP conjugate.

[0064] Cells were assessed using confocal microscopy to detect the fluorescence of GFP (Figures 3a and 3b). Images were collected sequentially using single line excitation (488 nm) with a Zeiss laser scanning confocal microscope (LSM-510).

[0065] In the absence of agonist, βarr-GFP was detected evenly distributed throughout the cytoplasm of cells expressing the V2R as indicated by the homogeneous βarr-GFP fluorescence in Figure 3a. Addition of arginine vasopressin (AVP, obtained from Sigma Chemicals, St. Louis, MO) promoted rapid redistribution of βarr-GFP from the cytoplasm to the receptor at the plasma membrane. A more prolonged exposure to the agonist (i.e., after 30 min.), βarr-GFP redistributed to endocytic vesicles (Figure 3b).

[0066] The upper confocal microscopy images of Figures 3a and 3b were taken at standard sensitivity and the intense energy emitted from detectable molecules localized in endocytic vesicles saturated the detector (i.e., when attempting to plot the intensities of the emissions captured as pixels, the intensities were off the scale). Figures 4a and 4b are identical to Figures 3a and 3b, respectively, except that they were taken at a reduced sensitivity to prevent saturation of the detector by βarr-GFP

colocalized in endocytic vesicles. Figures 4a and 4b demonstrate that concentration of βarr-GFP in endocytic vesicles produces spots of fluorescent intensity much greater than the fluorescent intensity observed in the cytoplasm of the control cells.

[0067] Using the non-saturated images (those in Figures 4a and 4b), the energy emissions were captured as pixels. The computer program IP Labs for Windows Version 3.0.6 (Scanalytics, Inc., Fairfax, VA) was used to analyze the data. The position and intensity of the pixels were mapped, generating a matrix. A histogram of pixel count versus pixel intensity was generated using the control cells. The mean intensity of the pixels in the control cells was calculated and a standard deviation was calculated.

[0068] The threshold intensity was calculated as the mean cell intensity plus three standard deviations (>99th percentile). Pixels with intensities above the threshold were indicated in a magenta color in both the control and treated images (Figures 5A and 5b, respectively). The control cells had very few magenta-colored pixels. In contrast, the cells treated with agonist (the treated cells) had many magenta-colored pixels. The magenta-colored pixels in the treated cells of Figure 5b closely correspond to the βarr-GFP containing endocytic vesicles in Figure 4b.

[0069] The pixels above the threshold in both the control cells and treated cells were tabulated. Figure 6 graphs the pixels in both the control cells and treated cells that are above the threshold. The first curve, labeled Control Cell, is a histogram of pixel count versus pixel intensity generated using the control cells. The second curve, labeled Vesicles, indicates pixels above the threshold in both the treated and control cells, and thus corresponds to vesicles in the treated cells. The threshold was set at the mean cell intensity of the control cells plus three standard deviations (>99th percentile).

[0070] Figure 7 is a graph of the number of pixels above the threshold intensity for the control and treated cells. The number of pixels above the threshold in the treated cells is approximately 120 times that of the control cells. This data readily may be used to indicate that an agonist was added and the βarr-GFP translocated to endocytic vesicles.

[0071] Various modifications and alterations of this invention will become apparent to those skilled in the art without departing from the scope and spirit of this invention.

These and other alternate embodiments are intended to fall within the scope of the claims which follow.

TABLE 1

Human G Protein Coupled Receptor Family

(Receptors known as of January, 1999)

CLASS	LIGAND	NUMBER	TISSUE	PHYSIOLOGY	THERAPEUTICS
•Class I					
Rhodopsin like					
	•Amine				
	•Acetylcholine				
	(muscarinic & nicotinic)	5	Brain, Nerves, Heart	Neurotransmitter	Acuity, Alzheimer's
	•Adrenoceptors				
	•Alpha Adrenoceptors	6	Brain, Kidney, Lung	Gluconeogenesis	Diabetes, Cardiovascular
	•Beta Adrenoceptors	3	Kidney, Heart	Muscle Contraction	Cardiovascular, Respiratory
	•Dopamine	5	Brain, Kidney, GI	Neurotransmitter	Cardiovascular, Parkinson's
	•Histamine	2	Vascular, Heart, Brain	Vascular Permeability	Anti-inflammatory, Ulcers
	•Serotonin (5-HT)	16	Most Tissues	Neurotransmitter	Depression, Insomnia, Analgesic
	• Peptide				
	•Angiotensin	2	Vascular, Liver, Kidney	Vasoconstriction	Cardiovascular, Endocrine
	•Bradykinin	1	Liver, Blood	Vasodilation,	Anti-inflammatory, Asthma
	•C5a anaphylatoxin	1	Blood	Immune System	Anti-inflammatory
	•Fmet-leu-phe	3	Blood	Chemoattractant	Anti-inflammatory

•Interleukin-8	1	Blood	Chemoattractant	Anti-inflammatory
•Chemokine	6	Blood	Chemoattractant	Anti-inflammatory
•Orexin	2	Brain	Fat Metabolism	Obesity
•Nociceptin	1	Brain	Bronchodilator, Pain	Airway Diseases, Anesthetic
•CCK (Gastrin)	2	Gastrointestinal	Motility, Fat Absorption	Gastrointestinal, Obesity, Parkinson's
•Endothelin	2	Heart, Bronchus, Brain	Muscle Contraction	Cardiovascular, Respiratory
•Melanocortin	5	Kidney, Brain	Metabolic Regulation	Anti-inflammatory, Analgesics
•Neuropeptide Y	5	Nerves, Intestine, Blood	Neurotransmitter	Behavior, Memory, Cardiovascular
•Neurotensin	1	Brain,	CNS	Cardiovascular, Analgesic
•Opioid	3	Brain,	CNS	Depression, Analgesic
•Somatostatin	5	Brain, Gastrointestinal	Neurotransmitter	Oncology, Alzheimer's
•Tachykinin				
(Substance P, NKA_1)	3	Brain Nerves	Neurohormone	Depression, Analgesic
•Thrombin	3	Platelets, Blood Vessels	Coagulation	Anti-coagulant, Anti-inflammatory
•Vasopressin-like	4	Arteries, Heart, Bladder	Water Balance	Anti-diuretic, Diabetic Complications
•Galanin	1	Brain, Pancreas	Neurotransmitter	Analgesics, Alzheimer's
•Hormone protein				
•Follicle stimulating hormone	1	Ovary, Testis	Endocrine	Infertility
•Lutropin-choriogonadotropic	1	Ovary, Testis	Endocrine	Infertility
•Thyrotropin	1	Thyroid	Endocrine	Thyroidism, Metabolism
•(Rhod)opsin				
•Opsin	5	Eye	Photoreception	Ophthalmic Diseases

•Olfactory	4(~1000)	Nose	Smell	Olfactory Diseases
•Prostanoid				
•Prostaglandin	5	Arterial, Gastrointestinal	Vasodilation, Pain	Cardiovascular, Analgesic
•Lysophosphatidic Acid	2	Vessels, Heart, Lung	Inflammation	Cancer, Anti-Inflammatory
•Sphingosine-1-phosphate	2	Most Cells	Cell proliferation	Cancer
•Leukotriene	1	White Blood Cells, Bronchus	Inflammation	Asthma, Rheumatoid Arthritis
•Prostacyclin	1	Arterial, Gastrointestinal	Platelet Regulation	Cardiovascular
•Thromboxane	1	Arterial, Bronchus	Vasoconstriction	Cardiovascular, Respiratory
•Nucleotide-like				
•Adenosine	4	Vascular, Bronchus	Multiple Effects	Cardiovascular, Respiratory
•Purinoceptors	4	Vascular, Platelets	Relaxes Muscle	Cardiovascular, Respiratory
•Cannabis	2	Brain	Sensory Perception	Analgesics, Memory
•Platelet activating factor	1	Most Peripheral Tissues	Inflammation	Anti-inflammatory, Anti-asthmatic
•Gonadotropin-releasing hormone like				
•Gonadotropin-releasing hormone	1	Reproductive Organs, Pituitary	Reproduction	Prostate Cancer, Endometriosis
•Thyrotropin-releasing hormone	1	Pituitary, Brain	Thyroid Regulation	Metabolic Regulation
•Growth hormone- inhibiting factor	1	Gastrointestinal	Neuroendocrine	Oncology, Alzheimer's
•Melatonin	1	Brain, Eye, Pituitary	Neuroendocrine	Regulation of Circadian Cycle
Class II				
Secretin like				
•Secretin	1	Gastrointestinal, Heart	Digestion	Obesity, Gastrointestinal

	•Calcitonin	1	Bone, Brain	Calcium Resorption	Osteoporosis
	•Corticotropin releasing factor/urocortin	1	Adrenal, Vascular, Brain	Neuroendocrine	Stress, Mood, Obesity
	•Gastric inhibitory peptide (GIP)	1	Adrenals, Fat Cells	Sugar/Fat Metabolism	Diabetes, Obesity
	•Glucagon	1	Liver, Fat Cells, Heart	Gluconeogenesis	Cardiovascular
	•Glucagon-like Peptide 1 (GLP-1)	1	Pancreas, Stomach, Lung	Gluconeogenesis	Cardiovascular, Diabetes, Obesity
	•Growth hormone- releasing hormone	1	Brain	Neuroendocrine	Growth Regulation
	•Parathyroid hormone	1	Bone, Kidney	Calcium Regulation	Osteoporosis
	•PACAP	1	Brain, Pancreas, Adrenals	Metabolism	Metabolic Regulation
	•Vasoactive intestinal polypeptide (VIP)	1	Gastrointestinal	Motility	Gastrointestinal
•Class III					
	•Metabotropic Glutamate	7	Brain	Sensory Perception	Hearing, Vision
	•$GABA_B$	1	Brain	Neurotransmitter	Mood Disorders
	•Extracellular Calcium Sensing	1	Parathyroid, Kidney, GI Tract	Calcium Regulation	Cataracts, GI Tumors

Figure 2

G protein-coupled receptors:

(Division into Class A or Class B)

1. **A1 adenosine receptor** [Homo sapiens]. ACCESSION AAB25533

npivyaf riqkfrvtfl kiwndhfrcq pappidedlp eerpdd

Class A

2. **adrenergic, alpha -1B-, receptor** [Homo sapiens]. ACCESSION NP_000670

npiiypcsskefkrafvrilgcqcrgrgrrrrrrrrrlggcaytyrpwtrggslersqsrkdsldd sgsclsgsqrtlpsaspspgylgrga pppvelcafpewkapgallslpapeppgrrgrhdsgplftfkllte pespgtdggasnggceaaadvangqpgfksnmplapg qf

Class A

3. **adrenergic receptor alpha-2A** [Homo sapiens]. ACCESSION AAG00447

npviytifnhdfrrafkkilcrgdrkriv

Class A

4. **alpha-2B-adrenergic receptor** - human. ACCESSION A37223

npviytifnqdfrrafrrilcrpwtqtaw

Class A

5. **alpha-2C-adrenergic receptor** - human. ACCESSION A31237

npviytvfnqdfrpsfkhilfrrrrrgfrq

Class A

6. **beta-1-adrenergic receptor** [Homo sapiens]. ACCESSION NP_000675

npiiycrspdfrkafqgllccarraarrrhathgdrprasgclarpgpppspgaasddddddvvgatpparllepwagcnggaaa dsd ssldepcrpgfaseskv

Class A

7. **beta-2 adr nergic r c pt r.** ACCESSION P07550

npliycrspdfriafqellclrrsslkaygngyssngntgeqsgyhveqekenkllcedlpgtedfvghqgtvpsdnidsqgrncstn

dsll

Class A

8. **dopamine receptor D1** [Homo sapiens]. ACCESSION NP_000785

npiiyafnadfrkafstllgcyrlcpatnnaietvsinnngaamfsshheprgsiskecnlvyliphavgssedlkkeeaagiarple

klspalsvildydtdvslekiqpitqngqhpt

Class A

9. **D(2) dopamine receptor.** ACCESSION P14416

npiiyttfniefrkaflkilhc

Class A

10. **d3 dopamine receptor** - human. ACCESSION G01977

npviyttfniefrkaflkilsc

Class A

11. **dopamine receptor D4** - human. ACCESSION DYHUD4

npviytvfnaefrnvfrkalracc

Class A

12. **dopamine receptor D5** - human. ACCESSION DYHUD5

npviyafnadfqkvfaqllgcshfcsrtpvetvnisnelisynqdivfhkeiaaayihmmpnavtpgnrevdndeeegpfdrmfq

iyqtspdgdpvaesvweldcegeisldkitpftpngfh

Class A

13. **muscarinic acetylcholine receptor M1** [Homo sapiens]. ACCESSION NP_000729

npmcyalcnkafrdtfrllllcrwdkrrwrkipkrpgsvhrtpsrqc

Class A

14. **muscarinic acetylcholine receptor M2** [Homo sapiens]. ACCESSION NP_000730

npacyalcnatfkktfkhllmchyknigatr

Class A

15. **muscarinic acetylcholine receptor M3 [Homo sapiens].**

npvcyalcnktfrttfkmlllcqcdkkkrrkqqyqqrqsvifhkrapeqal

Class A

16. **muscarinic acetylcholine receptor M4** [Homo sapiens]. ACCESSION NP_000732

npacyalcnatfkktfrhlllcqyrnigtar

Class A

17. **m5 muscarinic receptor.** locus HUMACHRM ACCESSION AAA51569

npicyalcnrtfrktfkmlllcrwkkkkveeklywqgnsklp

Class A

18. **5-hydroxytryptamine (serotonin) receptor 1A** [Homo sapiens]. ACCESSION BAA90449

npviyayfnkdfqnafkkiikckf

Class A

19. **5-hydroxytryptamine (serotonin) receptor 1B** [Homo sapiens]. ACCESSION BAA94455

npiiytmsnedfkqafhklirfkcts

Class A

20. **5-hydroxytryptamine (serotonin) receptor 1E** [Homo sapiens]. ACCESSION BAA94458

npllytsfnedfklafkklircre

Class A

21. **OLFACTORY RECEPTOR 6A1**. ACCESSION O95222

npiiyclmqevkralccilhlyqhqdpdpkkgsmv

Class A

22. **OLFACTORY RECEPTOR 2C1**. ACCESSION O95371

npliytlrnmevkgalrrllgkgrevg

Class A

23. **angiotensin receptor 1 [Homo sapiens].** ACCESSION NP_033611

nplfygflgkkfkryflqllkyippkakshsnl***s****f*km***s****fl****s***yrpsdnv***sss***tkkpapcfeve

Class B

24. **angiotensin receptor 2** [Homo sapiens]. ACCESSION NP_000677

npflycfvgnrfqqklrsvfrvpitwlqgkresmscrk***sss***lremetfvs

Class B

25. **interleukin 8 receptor beta (CXCR2)** [Homo sapiens]. ACCESSION NM_001557

NPLIYAFIGQKFRHGLLKILAIHGLISKDSLPKDSRPSFVG**SSS**GH**T**S**TT**L

Class B

26. **cx3c chemokine receptor 1** (cx3cr1) (fractalkine receptor)

ACCESSION P49238

npliyafagekfrrylyhlygkclavlcgrsvhvdf***sss****es*qrsrhg***s***vl***ss***nftyhtsdgdallll

Class B

27. **neurotensin receptor - human.** ACCESSION S29506

n pilynlvsanfrhiflatlaclcpvwrrrrkrpafsrkad***s****v****ss***nh***fl****ss***natretly

Class B

28. **SUBSTANCE-P RECEPTOR (SPR)** (NK-1 RECEPTOR) (NK-1R). ACCESSION P25103

npiiyccl**n**drfrlgfkhafrccpfisagdyeglemkstrylqtqgsvykvsrle***tt****is****t***vvgaheeepedgpka***t****p****ss***ldltsnc***ss***r

sd***s***ktmte***s****f****s****f****ss***nvls

Class B

29. **vas pressin receptor type 2** [Homo sapiens]. ACCESSION AAD16444

npwiyasfsssvsselrsllccargrtppslgpqde***sc******tt***a***sss***lakd***tss***

Class B

30. **thyrotropin-releasing hormone receptor** - human. ACCESSION JN0708

npviynlmsqkfraafrklcnckqkptekpanysvalnysvikesdhf***st***elddi***tv******t***d***t***y***s***a***t***kvsfddtclasevsfsqs

Class B

31. **oxytocin receptor - human.** ACCESSION A55493

npwiymlftghlfhelvqrflccsasylkgrrlget***s***a***s***kk***s***n***sss***fvl***s***hr***sss***qr***s***c***s***qpsta

Class B

32. **neuromedin U receptor 1 [Homo sapiens].** ACCESSION AAG24793

npvlyslmssrfretfqealclgacchrlrprh**sshslsrmttgstl**cdvgslgswvhplagndgpeaqqetdps

Class B

33. **gastrin receptor.** ACCESSION AAC37528

nplvycfmhrrfrqacletcarccprpprarpralpdedpp**tpsiaslsrlsyttistl**gpg

Class B

34. **galanin receptor 3 [Homo sapiens].** ACCESSION 10879541

nplvyalasrhfrarfrrlwpcgrrrrhrarralrrvrpassgppgcpgdarpsgrllagggqgpepregpvhggeaargpe

Class A

35. **edg-1** - human. ACCESSION A35300

npiiytltnkemrrafirimscckcpsgdsagkfkrpiiagmefsrsksdnsshpqkdegdnpetimssgnvnsss

Class A

36. **central cannabinoid receptor** [Homo sapiens]. ACCESSION NP_057167

npiiyalrskdlrhafrsmfpscegtaqpldnsmgdsdclhkhannaasvhraaescikstvkiakvtmsvstdtsaeal

Class A

37. **delta opioid r ceptor -** human. ACCESSION I38532

npvlyafldenfkrcfrqlcrkpcgrpdpssfsrpreatarervtactpsdgpgggraa

Class A

38. **proteinase activated receptor 2 (PAR-2) human**. ACCESSION P55085

dpfvyyfvshdfrdhaknallcrsvrtvkqmqv**slts**kkhsrk**sssysssstt**vk**tsy**

Class B

39. **vasopressive intestinal peptide receptor (VIPR) rat**. ACCESSION NM_012685

NGEVQAELRRKWRRWHLQGVLGW**SSK**SQHPWGGSNGA**TCST**QVSMLTRVSPSARR

SSSFQAEVSLV

Class B